Public Interest Energy Research (PIER) Program
INTERIM REPORT

SOLAR REFLECTANCES OF ROOFS COVERED WITH MINERAL AGGREGATE SURFACING MATERIAL

Prepared for: California Energy Commission
Prepared by: Heat Island Group, Lawrence Berkeley National Laboratory

OCTOBER 2012
CEC-500-2012 -083

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Contract Number: 500-10-052

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ACKNOWLEDGEMENTS

The authors appreciate the assistance in preparation of this report provided by the following people:

- Mr. Louis Medina, A-1 Grit Company
- Mr. Harold Newman, A-1 Grit Company
- Ms. Amber Dobson, A-1 Grit Company
- Mr. Payam Bozorgchami, California Energy Commission

PREFACE

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Solar Reflectances of Roofs Covered with Mineral Aggregate Surfacing Material is a task report for the Urban Heat Island Mitigation Phase 2 activity of National Labs Buildings Energy Efficiency Research Projects (Contract Number 500-10-052), conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program.

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ABSTRACT

The Heat Island Group at Lawrence Berkeley National Laboratory measured the solar reflectances of roofs covered with mineral aggregate surfacing materials from the A-1 Grit Company. This measurement determines how strongly the roofing material reflects sunlight in order to minimize heat gain into the building. Solar reflectance refers to the fraction of solar energy that is reflected by the roof. Reflectance tests were conducted following American Society for Testing & Materials (ASTM) Standard E1918-06, "Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field." Measurements on roofs aged 1 to 20 years were performed at four sites in the Los Angeles area. Solar reflectances ranged from about 0.52 (newest roof) to 0.48 (oldest roof). This was not a controlled experiment, since the aggregates were quarried at different times and the roofs were in distinctly different environments. However, the measurements suggest that the aggregate material retains at least 90 percent of its initial solar reflectance over a 20-year period. The longer the roofing material can maintain its original reflectance, the more persistent the energy savings and cost savings to building owners and occupants. This interim report will be included as one of the documents used in evaluating an alternative compliance option for aggregate roofing products in the State's Building Energy Efficiency Standards (Title 24, Part 6). Approval of an alternative compliance option could provide California ratepayers, building owners, roofing manufacturers and installers with another option for meeting California's Building Energy Efficiency Standards for roof replacement.

Keywords: California Energy Commission, Lawrence Berkeley National Laboratory, Heat Island Group, A-1 Grit, cool roofs, aging, aggregate, solar radiation, solar reflectance, thermal emittance, ASTM Standard E1918-06, test method, pyranometer, Cool Roof Rating Council

Please use the following citation for this report:

Rosado, Pablo, Melvin Pomerantz, Ronnen Levinson (Lawrence Berkeley National Laboratory). 2012. ***Solar Reflectances of Roofs Covered with Mineral Aggregate Surfacing Material.*** California Energy Commission. Publication Number: CEC-500-2012-083.

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EXECUTIVE SUMMARY

Introduction

Measurements of the aged solar reflectance of mineral aggregate roof surfacing materials are needed to update the Title 24 Building Energy Efficiency Standards. These Standards prescribe the minimum energy efficiency requirements for newly constructed buildings and additions and alterations to existing buildings, including installation of roofing material, either new or as a replacement. The Heat Island Group at Lawrence Berkeley National Laboratory (LBNL) measured the solar reflectances of roofs surfaced with aggregate from the A-1 Grit Company. The aggregate was limestone (a.k.a. white marble), sold as 3/8” natural white rock.

Purpose

This study sought to measure how the solar reflectances of roofs surfaced with this aggregate vary with age.

Methodology

Test measurements followed the American Society of Testing and Materials (ASTM) Standard E1918-06, “Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field” (ASTM 2006). This method uses a pyranometer to measure the solar reflectance of various horizontal and low-sloped surfaces and materials in the field. A pyranometer was used to measure the solar reflectances of aggregate-surfaced roofs on four buildings in the Los Angeles area. The ages of the roofs ranged from about 1 to 20 years.

Outcomes

Solar reflectance was calculated as the ratio of reflected radiation to incoming radiation with 1 being totally reflective and 0 being non reflective. The solar reflectances of the four aggregate-surfaced roofs ranged from about 0.52 (newest) to 0.48 (oldest). Values decreased slightly with age, with the most rapid decrease occurring within the first five years. Although the roofs were in distinctly different environments, results suggest that this aggregate retains at least 90 percent of its initial solar reflectance over 20 years.

Benefits to California

Based on the small set of roofs tested, the solar reflectance of this light-colored aggregate material is quite stable over about two decades. This suggests that it is reasonable to approximate the initial and three-year aged solar reflectances of this aggregate at 0.50. This information can be incorporated in the State’s Building Energy Efficiency Standards (Title 24, Part 6) until further data on the aging of roofing aggregate are available. This provides an alternative compliance option for aggregate roofing products in the State’s efficiency standards. Approval of an alternative compliance option could provide California ratepayers, building owners, roofing manufacturers and installers with another option for meeting the efficiency standards for roof replacement.

Recommendations

The current study measured the solar reflectances of only four aggregate-surfaced roofs, all of which used the same type of aggregate. Using this result to advise the building energy efficiency standard should be regarded as an interim measure. A longer-term goal of the California Energy Commission should be to support development of a practical method to determine the initial and aged solar reflectances of aggregate roofing materials that requires neither rooftop measurements nor the transportation of large test beds to/from exposure sites. Such a method could be proposed to the Cool Roof Rating Council (CRRC) for inclusion in its CRRC-1 Product Rating Program. The CRRC is an independent organization that lists the solar reflectance and thermal emittance specifications for many roofing products.

Section 118(i) of the Title 24 Building Energy Efficiency Standards requires all roof products to meet a specified solar reflectance and thermal emittance that is tested, certified and labeled according to procedures of the CRRC. In order to receive a product rating by the CRRC the manufacturer or company that sells the finished product must meet the criteria of the CRRC's product rating program. As an example, for each “Standard Roof Product” to be tested manufacturers must prepare a total of nine samples randomly selected from two batches representing the finished roofing product. Upon completed testing for the initial solar reflectance and thermal emittance, three product samples are then shipped by the testing laboratory to each of the three approved CRRC test farms for completion of three-year aged exposure testing. The three test farms are regionally located across the US representing different climate regions.

CHAPTER 1: Introduction

California's *2008 Title 24 Building Energy Efficiency Standards* (California Energy Commission 2008) prescribe minimum values of aged solar reflectance for roofs on some buildings. The Efficiency Standards specify that the aged solar reflectances of roofing products shall be determined in accordance with the CRRC-1 Product Rating Program of the Cool Roof Rating Council (CRRC 2012). In the CRRC-1 program, the aged solar reflectances of roofing products are nearly always tested by using a laboratory instrument—a hemispherical solar reflectometer—to characterize small product coupons (each about 10 cm × 10 cm) that have been naturally exposed for three years at designated sites in Arizona, Ohio, and Florida.

It is impractical to measure the solar reflectance of aggregate roofing surface materials with the reflectometer because the roughness scale of the aggregate (about 1 cm) is comparable to the 2.5 cm diameter of the instrument's aperture. At present, the only CRRC-1 approved test method suitable for determining the solar reflectance of aggregate roofing surface materials uses a pyranometer (sunlight meter) to measure the solar radiation incident on and reflected from an aggregate bed that is at least 4 m in diameter. Logistical difficulties associated with transporting undisturbed large beds of aggregate to and from the CRRC-1 designated exposure sites have impeded testing of their aged solar reflectances.

In the absence of CRRC-1 ratings for the aged solar reflectance of roofing aggregate, it is helpful to characterize the effect of aging on the solar reflectance of these products by means of in-situ measurements on existing roofs. To that end, the Heat Island Group at Lawrence Berkeley National Laboratory (LBNL) measured the solar reflectances of several roofs covered with aggregate surfacing material. The aggregate was limestone (a.k.a. white marble), sold by the A-1 Grit Company as 3/8″ Natural White Rock. This light-colored product was chosen because past research suggests that, all else being equal, loss of solar reflectance is typically greatest for light-colored materials whose initial solar reflectance is high (Sleiman et al. 2011).

CHAPTER 2:
Project Approach

2.1 Test Method

Test measurements followed the American Society of Testing and Materials (ASTM) Standard E1918-06, “Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field” (ASTM 2006). This method uses a pyranometer to measure the solar reflectance of various horizontal and low-sloped surfaces and materials in the field. It is intended for use when the sun is high enough to make the sun angle to the normal from the tested surface less than 45 degrees. The method is well-suited to measuring the solar reflectance of large surfaces, including those that have rough surfaces.

2.2 Locations

Figure 1 maps the locations and ages of the roofs evaluated in the project. Table 1 details their addresses and ages.

Figure 1: Map Showing Site Name, Location, and Age of Each Tested Roof

Table 1: Site Name, Address, and Age of Each Tested Roof

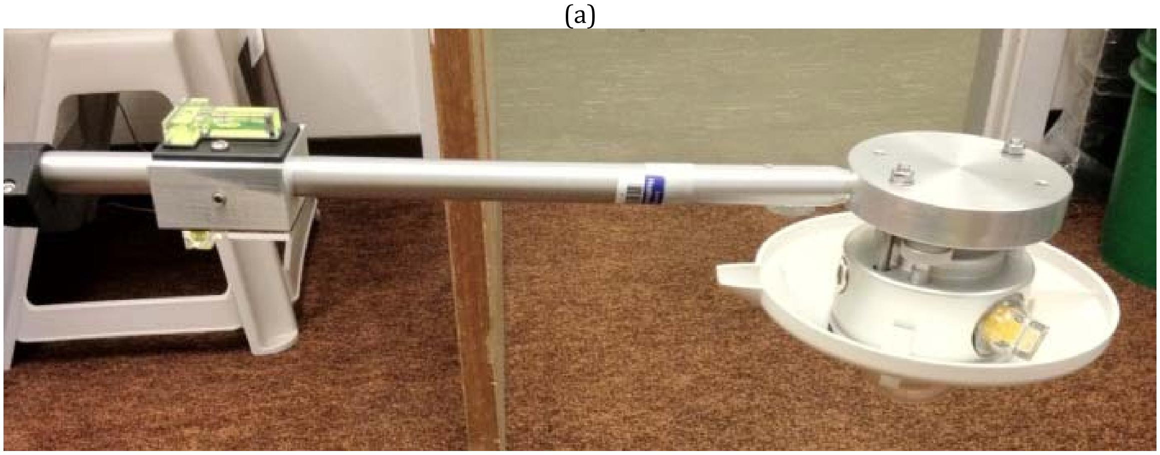
Site (#): Name	Address	Roof age in 2012 (y)
1. Calvary Chapel	2200 East Colorado Boulevard Pasadena, CA 91107	6-7
2. Lutheran Church	7070 Palm Avenue Highland, CA 92346	1-2
3. Private Residence	35441 Beach Road Capistrano Beach, CA 92624	19-20
4. Leisure World	5552 Rayo Del Sol Laguna Woods, CA 92637	4-5

2.3 Apparatus

Solar radiation was measured with a Kipp & Zonen CMP6 first-class pyranometer (Figure 2; Table 2.) Pyranometer output was read from a Kipp & Zonen Meteon display meter having a resolution of 1 watt per square meter (W/m^2). The pyranometer and display meter were calibrated by the manufacturer in November 2011 and September 2011, respectively, about 4-6 months before the roof reflectances were measured in March 2012.

Figure 2: The Kipp & Zonen CMP6 First-Class Pyranometer

(a)



(b)

The instrument, (a black thermopile sensor surrounded by a double glass dome and a white plastic solar shield) is shown (a) facing upward and (b) facing downward. A rectangular block attached to the pyranometer's mounting fixture has two cross level assemblies—one to level the instrument when facing up, and the other to level the instrument when facing down.

Table 2: Specifications of the Kipp & Zonen CMP6 First-Class Pyranometer

Spectral range	0.285 - 2.800 µm
Max. solar irradiance	2000 W/m^2
Response time	18 seconds
Sensitivity	14.03 µV/W/m^2 (micro volts per watt per meter squared)

A Hercules Quick-N-EZ microphone stand was used to support the pyranometer 50 cm above the roof's surface. The pyranometer's mounting fixture is fitted with two cross-level assemblies mounted on opposite sides of a metal block (Figure 2.)

Each assembly contains a pair of perpendicular spirit levels that gauge pitch and roll (Figure 3.) When the pyranometer faces up, the instrument is leveled with the assembly that is parallel to the pyranometer's radiation sensor. When the pyranometer faces down, the instrument is leveled with the assembly that is antiparallel to the sensor.

Figure 3: Cross-Level Assembly Contains a Pair of Perpendicular Spirit Levels That Are Used to Verify That a Plane Is Horizontal

2.4 Sampling and Trials

Measurements were performed in March 2012 on low-sloped dry roofs (Figures 4 through 7 are photographs of the roofs tested.) On each rooftop, at least three pairs of incident and reflected radiation measurements were recorded at each of three widely spaced areas. (Site 1, the first building visited, was an exception. This roof was partially dry initially; it had rained the previous days. Measurements were taken when the roof appeared to be dry. The time required for drying and intermittent sunshine permitted only two pairs of solar reflectance measurements.) As specified by the ASTM Standard E1918-06, tested areas on each roof were separated by more than 10 times the height of the sensor above the surface (that is, were at least 5 m apart), and each area was at least 4 m in diameter.

Figure 4: Pyranometer Measuring Solar Radiation Incident on the Roof of the Calvary Chapel (Site 1)

A weight hanging from the opposite end of the support arm counterbalanced the pyranometer. Note the broken cloud cover that slowed the testing; only two areas could be properly measured at this site. (Image source: LBNL)

Figure 5: Lutheran Church (Site 2)

The tested aggregate was on the low-slope roof surface shown in the foreground. (Image source: LBNL)

Figure 6: Roof of the Beachfront Private Home (Site 3)

Image source: LBNL

Figure 7: Pyranometer Measuring Solar Radiation Incident on the Roof of Leisure World (Site 4).

Image source: LBNL

2.5 Procedure

Weather on each day was cloudy with sporadic haze. Measurements presented here were taken during intervals when the sun was unobscured and the solar flux was not changing rapidly. Measurements were performed between 10:40 and 15:15 Pacific Daylight Saving Time (PDT) to ensure that the angle of the sun to the normal from the surface was less than 45 degrees. Solar elevation angle was computed with the NREL SOLPOS solar position calculator (NREL 2012).

The instrument stand was aligned to point the pyranometer's support arm toward the sun, and the observer stood at least 3 m behind the instrument stand. This removed the shadow of the observer from the test area, and reduced the instrument's view of the shadow cast by the equipment. The pyranometer was leveled horizontally prior to each measurement of incident or reflected radiation.

The pyranometer was faced upward to measure incident sunlight, and then downward to measure reflected sunlight. Before recording each pyranometer measurement, the sensor was allowed to equilibrate for thirty seconds, and each reading was confirmed steady for at least 10 seconds. Each pair of incoming and reflected radiation measurements was completed within 2 minutes. Solar reflectance was calculated as the ratio of reflected radiation to incoming radiation.

Three solar reflectance measurements were taken on each roof at each of the three different areas. This yielded nine pairs of solar radiation measurements per roof. The only exception occurred at Site 1, where drying of the wet surface and cloudy skies left time for only two areas to be tested (see Figure 4 and Figure 8), for a total of six pairs of radiation measurements. The letters indicate the measurement locations and the order that the roof measurements were taken.

Figure 8: Only Two Test Areas (A and B) Were Measured on the Roof of the Calvary Chapel (Site 1) Because the Roof Started Partially Wet and Skies Were Partly Cloudy

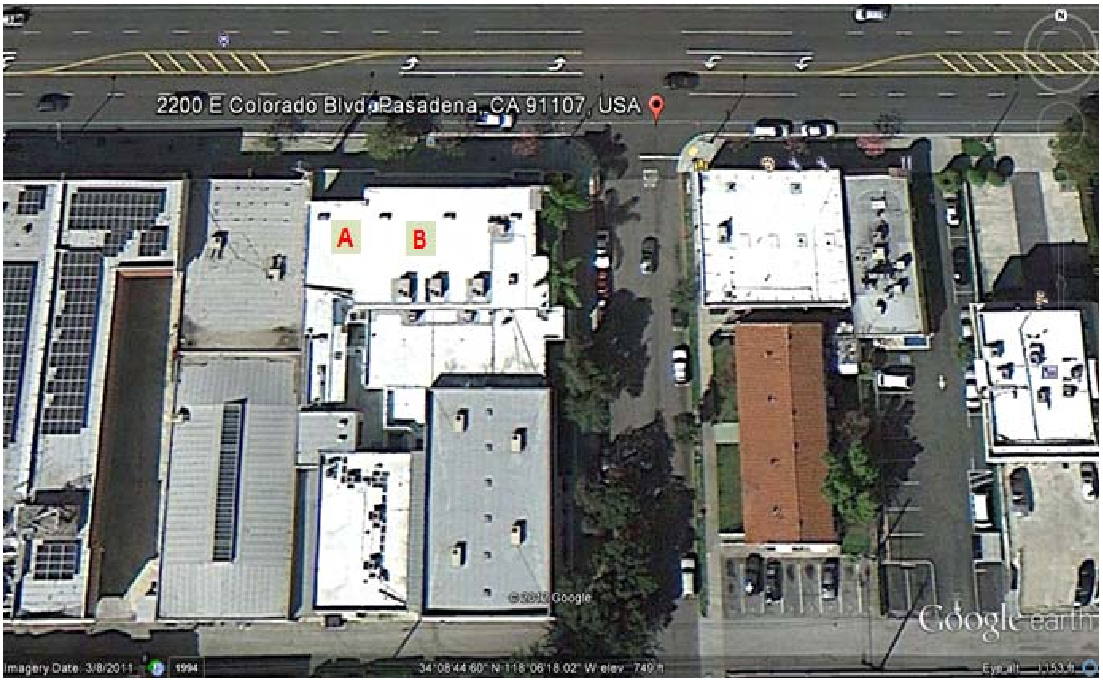


Image source: Google Earth, modified

Figure 9: Test Areas A, B, and C on the Roof of the Lutheran Church (Site 2) Were Clear of the Shadows Cast by Trees and by the Steep Roof in the Middle of the Building

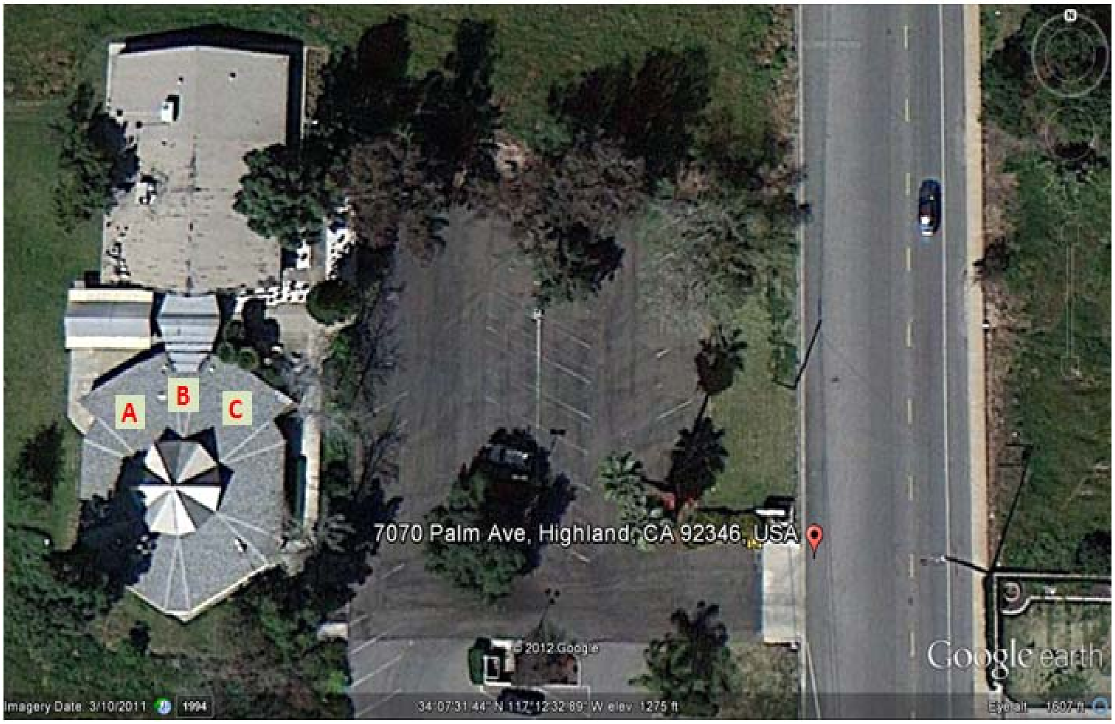


Image source: Google Earth, modified

Figure 10: Test Areas A, B, and C on the Roof of the Private Home (Site 3)

Image source: Google Earth, modified

Figure 11: Test Areas A, B, and C on the Roof of Leisure World (Site 4)

Image source: Google Earth, modified

CHAPTER 3:
Results

Table 3 summarizes the results obtained by this study.

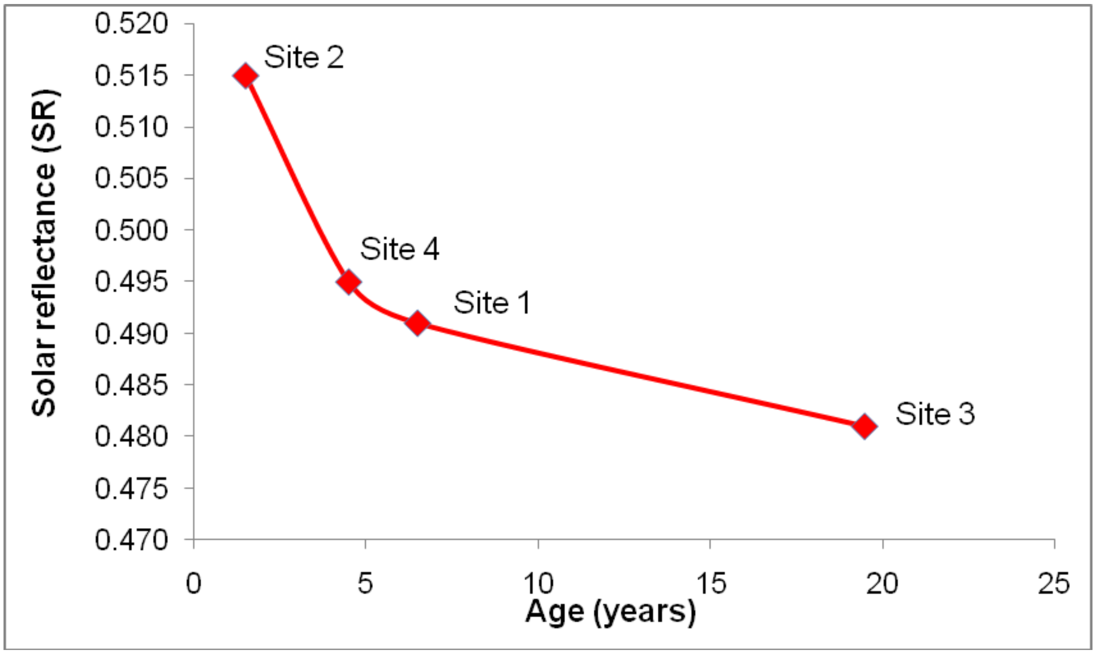
Table 3: Solar Reflectances, Ages, and Measurement Dates of Tested Roofs

Site **Age (y)** Date (2012)	Trial	Solar Reflectance			
		Area A	Area B	Area C	Overall Mean
#1 **6-7** March 26	1st	0.495	0.485	N/A	
	2nd	0.494	0.488	N/A	
	3rd	0.500	0.482	N/A	
	Span (max - min)	*0.006*	*0.006*	N/A	
	Mean	**0.496**	**0.485**	N/A	**0.491**
#2 **1-2** March 27	1st	0.515	0.526	0.508	
	2nd	0.509	0.523	0.508	
	3rd	0.504	0.530	0.510	
	Span (max - min)	*0.011*	*0.007*	*0.002*	
	Mean	**0.509**	**0.527**	**0.509**	**0.515**
#3 **19-20** March 27	1st	0.499	0.479	0.466	
	2nd	0.502	0.480	0.459	
	3rd	0.502	0.481	0.462	
	Span (max - min)	*0.003*	*0.002*	*0.007*	
	Mean	**0.501**	**0.480**	**0.462**	**0.481**
#4 **4-5** March 28	1st	0.503	0.493	0.498	
	2nd	0.494	0.496	0.496	
	3rd	0.495	0.489	0.493	
	Span (max - min)	*0.009*	*0.007*	*0.005*	
	Mean	**0.497**	**0.493**	**0.496**	**0.495**

3.1 Discussion

The solar reflectances ranged from 0.52 to 0.48, with a mean value of 0.50. The roof with the most recently installed aggregate material (Site 2, age 1-2 y) had the highest solar reflectance (0.52), while that with the oldest aggregate (Site 3, age 20 y) had the lowest solar reflectance (0.48). The largest difference in solar reflectance was 0.034, between Sites 2 and 3, where the age span is about 19 years. Figure 12 plots solar reflectance versus age for the four sites, and suggests that the solar reflectance decreases most rapidly within the first five years.

Figure 12: Aggregate Roof Solar Reflectance Versus Age



Note that this was not a controlled experiment. The aggregates used for roofing materials were quarried at different times, and the roofs were in distinctly different environments. Soiling, wind and rain may differ from site to site, even within the same climate zone. Nevertheless, the solar reflectances of all four roofs were within 10 percent of 0.50.

While the thermal emittances of these roofs were not measured, it is expected that the thermal emittance of an aggregate roof would be at least 0.90 (see Appendix A).

CHAPTER 4:
Conclusion

Even though the weather was cloudy during much of the testing, there were enough sunny intervals to permit proper determination of the solar reflectances. The solar reflectances of the tested roofs covered with A-1 Grit roofing aggregate surfacing material for 1 to 20 years ranged from about 0.52 to 0.48. Solar reflectance decreased slightly with the age of the roof. Although roofs were in distinctly different environments, our results suggest that this aggregate retains a solar reflectance of about 0.50 within 10 percent over a 20-year period.

CHAPTER 5: References

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APPENDIX A:
Thermal Emittance of Aggregate Roofing

The thermal emittance of aggregate roofing was not measured because the commonly used and Cool Roof Rating Council-approved method for measurement of thermal emittance, ASTM Standard C1371 (ASTM 2010), is not readily applied to aggregate roofing materials. However, the authors estimate as follows that the thermal emittance of aggregate roofing materials should be at least 0.90.

Table A.11 of the text by Incropera and DeWitt (1985) reports that the hemispherical thermal emittance of rock is typically 0.88 - 0.95. It does not specify whether this rock is solid or crushed. However, since a bed of aggregate will be rougher than the solid rock from which the aggregate is crushed, and roughness increases absorptance, the thermal absorptance of an aggregate bed will exceed that of its solid rock source. Since thermal emittance equals thermal absorptance (Kirchhoff's law), increasing solar absorptance increases thermal emittance. Hence, the thermal emittance of a bed of unsoiled aggregate should be not less than 0.88 - 0.95, and we assume that its roughness will make it at least 0.90.

The agents that soil roofs, including soot, dirt, and biological growth, typically have thermal emittances of at least 0.90 (emissivity table on p. 10-282 of Lide 1990, value for soot; Table A.11 of Incropera and DeWitt 1985, values for dirt and vegetation). Therefore, the research team estimates that the thermal emittance of an aggregate bed, whether new or soiled, should be at least 0.90.